

AN INVESTIGATION OF ELECTRETS

A THESIS

Presented to  
the Faculty of the Division of Graduate Studies  
Georgia Institute of Technology

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science in Electrical Engineering

by  
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May 1951

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## AN INVESTIGATION OF ELECTRETS

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Date Approved by Chairman May 29, 1951

## ACKNOWLEDGEMENT

On the completion of this work the author wishes to express his sincere thanks to Professor M. A. Honnell, not only for his suggestion of the problem, but also for his most valuable aid and guidance in its prosecution.

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# AN INVESTIGATION OF ELECTRETS

## I

### INTRODUCTION

An electret is a dielectric material which has been so treated that it exhibits a permanent positive charge on one surface and negative charge on the other. It is surrounded by electrostatic lines of force just as a magnet is surrounded by magnetic lines of force, and a close analogy would be to call it the electrostatic equivalent of a permanent magnet.

This thesis has for its purpose the following:

1. To present in concise, detailed form information necessary to produce electrets.
2. To present new information found from research by the author.
3. To suggest several useful applications for electrets.

## II

## HISTORY

The possibility of the existence of electrets was first discussed by Michael Faraday in his Experimental Researches in Electricity, 1839. The next mention of electrets in the literature was in Oliver Heaviside's Electrical Papers, Vol. I, p. 488, 1925. Although Heaviside never made an electret, he gave a fairly complete discussion on the subject and coined the word "electret" to fit in with its similarity to a "magnet." The first record of the production of an electret was that reported in 1925 by Professor Mototaro Eguchi of Tokyo, Japan. Since then a number of men have experimented with electrets and have reported their findings in various articles. A complete list of articles written on the subject to date is contained in the bibliography at the end of this thesis.

Thus far, the only general use that has been made of electrets was by the Japanese during World War II in condenser microphones. Many other uses have been suggested. A few patents have been taken out in Britain on the use of electrets in electrical measuring instruments. A discussion of several uses of electrets will be given in Chapter VI.



## III

## PRODUCTION OF ELECTRETS

This chapter describes the methods used in the production of electrets, with particular attention placed on points of importance that should be observed by future workers in the field. It is hoped that this information will allow other researchers to put the routine apparatus into operation in a minimum of time.

The general procedure for producing electrets is as follows:

The material to be made into an electret is subjected to a high temperature between two metal electrodes. When sufficient heat has been applied (to reach the melting temperature in the case of wax electrets) a high potential is applied to the electrodes. The electret is then allowed to cool at which time the potential is removed along with the electrodes, leaving a completed electret.

The apparatus employed to produce electrets is shown in the photograph of Fig. 1. A hot plate type of oven with a heat control is used as the base. If substances with very high melting points are to be used in the making of the electrets, it may be necessary to place the apparatus in a high temperature oven, but very little change of basic design need be made.

All surfaces of the structure are rounded to some degree to prevent corona discharge. In particular, the surfaces of the top and bottom electrodes are well rounded to prevent arc-over between them. Good quality insulation is used throughout in order to keep leakage currents to a minimum, and thus insure as high a voltage as possible from the

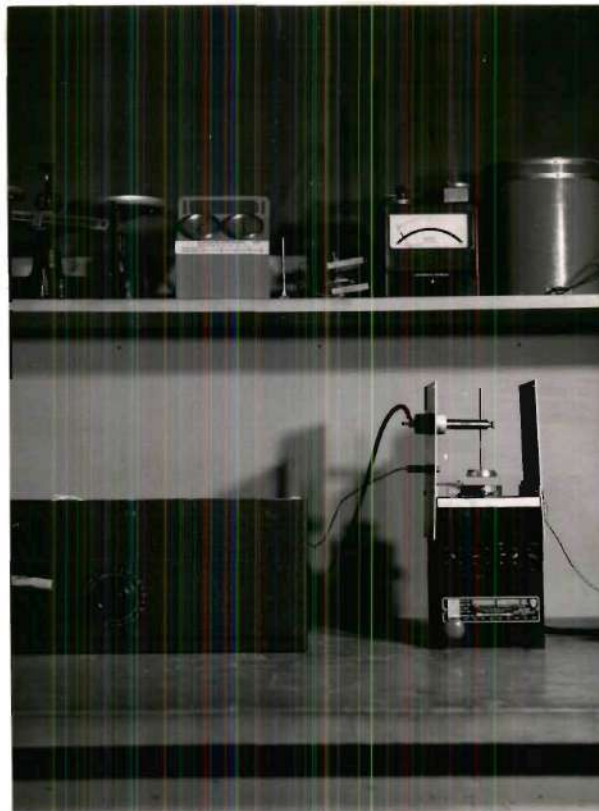
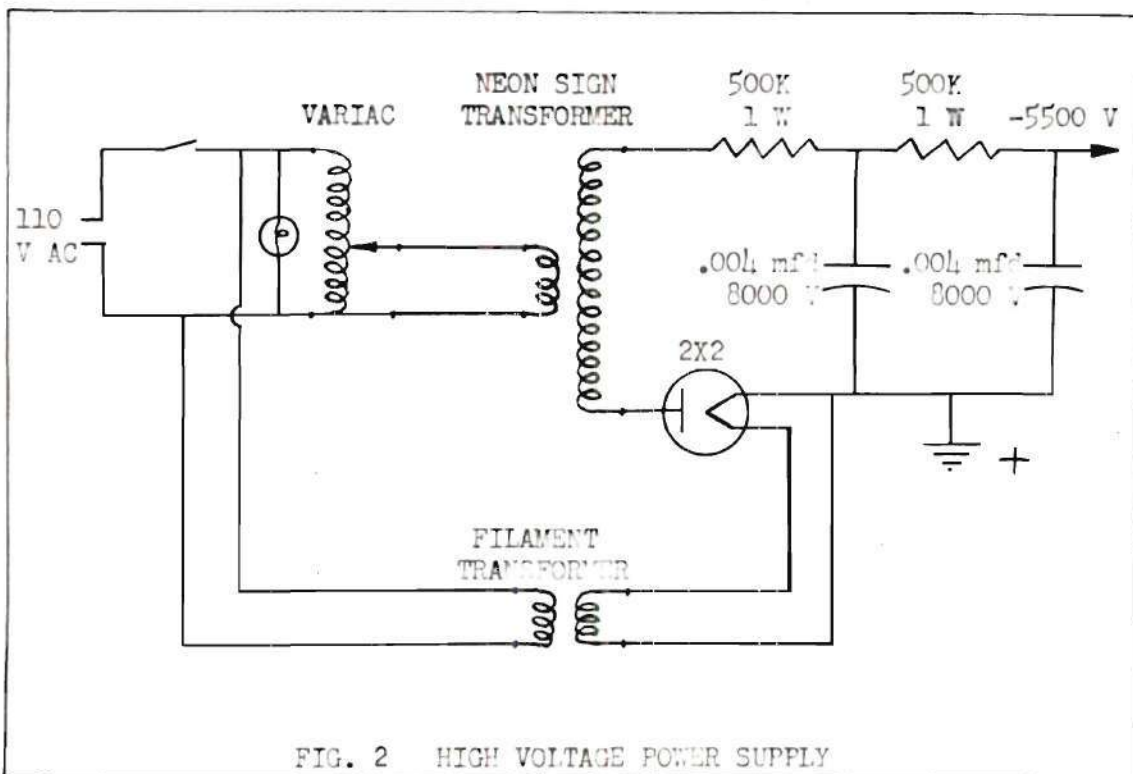


FIG. 1 APPARATUS USED IN PRODUCTION OF ELECTRETS





power supply.

A schematic diagram of the power supply is illustrated in Fig. 2. A neon sign transformer, as used here, makes a very convenient source of high voltage. Other types of high voltage transformers may be used because the current ordinarily drawn is extremely small. In this power supply, ground was made positive so that the filament transformer need not have special high voltage insulation. A Variac is employed in order that the output voltage may be conveniently adjusted to the optimum value for the production of electrets of varying thicknesses and materials.

The following are materials used by the author in the production of four different types of electrets:

Material	Quantity	Approximate size of completed electret	
		Thickness	Diameter
1. Carnauba Wax (yellow) - 70% by weight		.2 in.	1.5 in.
Paraffin - 30% by weight			
2. Carnauba Wax (yellow) - 50% by weight		.2 in.	1.5 in.
Beeswax - 50% by weight			
3. Carnauba Wax (yellow) - 50% by weight		.2 in.	1.5 in.
Rosin			
4. Plexiglass (methyl methacrylate polymer)		.125 in.	1.5 in.

Carnauba wax and plexiglass give permanent polarization. Beeswax and paraffin give no polarization, and rosin gives temporary polarization. The beeswax, paraffin, and rosin are mixed with the carnauba wax to prevent it from cracking upon cooling.

The carnauba wax electrets are made as follows:

Carnauba wax and beeswax (or rosin, or paraffin) are placed in the bottom electrode dish and heated to a molten state, stirred, and the top electrode is lowered until it just touches the surface of the mixture. A close-up view of the apparatus in this position is shown in Fig. 3. Care should be taken to remove bubbles in the bottom or at the surface of the mixture as they will cut down on the field strength of the completed electret. Bubbles can be kept to a minimum by keeping the heat below the boiling point of the substance used. The electrodes are covered with aluminum foil to prevent the electret from sticking to the dish when completed. The high potential is applied while the substances are in the molten state and is not removed until the electret has completely cooled.

In preparing plexiglass electrets the bottom electrode is turned upside down to provide a flat surface. It has been found that the use of a thin dielectric material with a high melting point placed on each side of the plexiglass as illustrated in Fig. 4 provides a more even field on each side of the electret. This also allows the use of larger electrodes so that the entire material is subjected to the electric field. Plexiglass is heated only to the point of softening and kept in this state for approximately two hours in the electrostatic field. If too much heat is used the plexiglass attaches itself firmly to the adjoining material and cannot be removed without completely destroying the finished electret.

The completed electrets should be kept wrapped in tinfoil or aluminum foil when not in use. It is convenient to keep the electrets

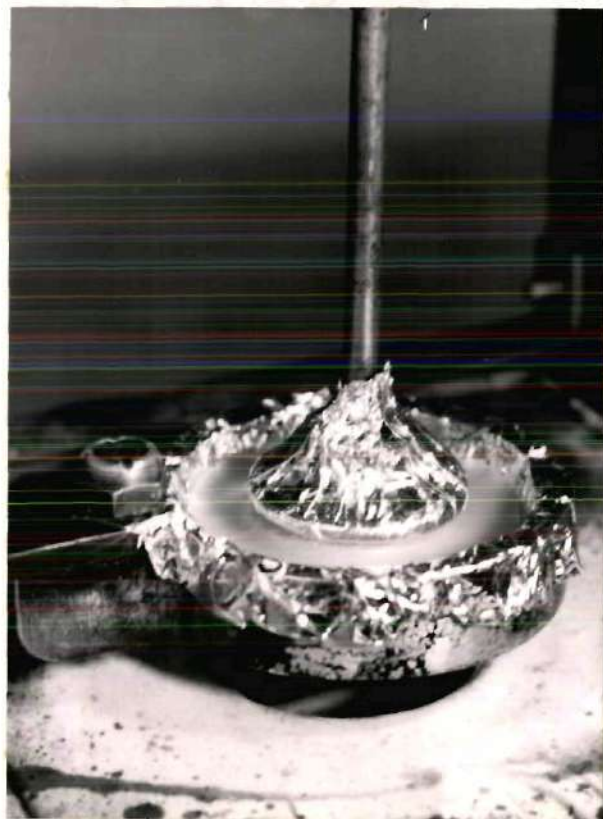


FIG. 3  
PRODUCTION OF WAX ELECTRET

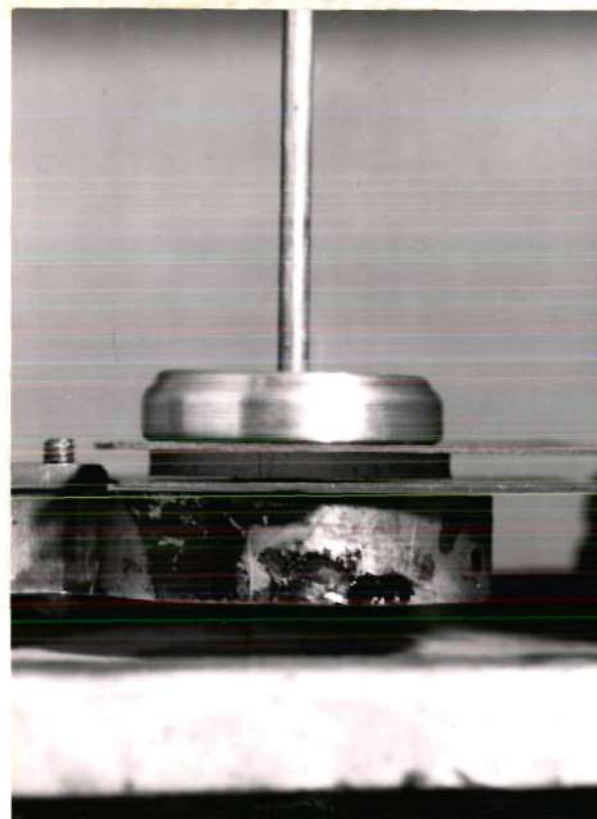


FIG. 4  
PRODUCTION OF PLEXIGLASS ELECTRET

in an airtight jar containing silica gel. Care should be taken not to contaminate the surfaces by constant handling.



## IV

## DIELECTRIC CONSTANT MEASUREMENTS

An attempt was made to determine whether or not there is a change in the dielectric constant of plexiglass before and after polarization. The general method used was to note the change in capacitance of a parallel plate condenser when the electret was placed between the plates. The arrangement used is shown in Fig. 5.

A Q-meter was used to measure the capacitance of the parallel plate assembly. The measurements were taken at one particular frequency throughout each test. The circuit was resonated by varying the standard condenser with and without the electret between the parallel plate assembly. The difference in capacitance was recorded and the dielectric constant calculated from this change in capacitance.

The plates were made considerably larger than the diameter of the electrets so as to reduce fringing effects. All connecting leads were made short and rigid, and great care was exercised to insure that the change in capacitance was due only to the insertion of the dielectric material in the test assembly.

Due to a slight deformation of the electrets, caused by heating, it was found necessary to space the plates a measured distance apart greater than the thickness of the nonpolarized material. This deformation, illustrated in Appendix I, did not change the thickness or diameter of the electret. The air space between the electret and the upper plate was considered to be an air dielectric condenser in series with a condenser whose dielectric is the plexiglass wafer. To illustrate the

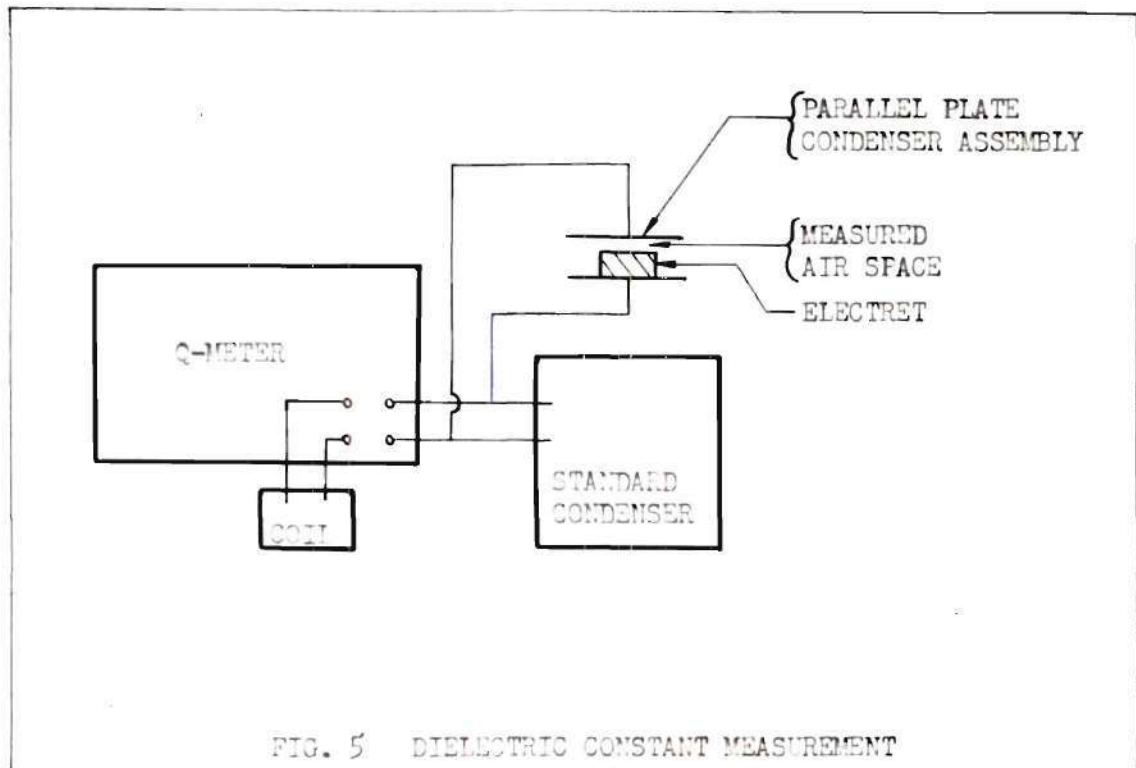


FIG. 5 DIELECTRIC CONSTANT MEASUREMENT

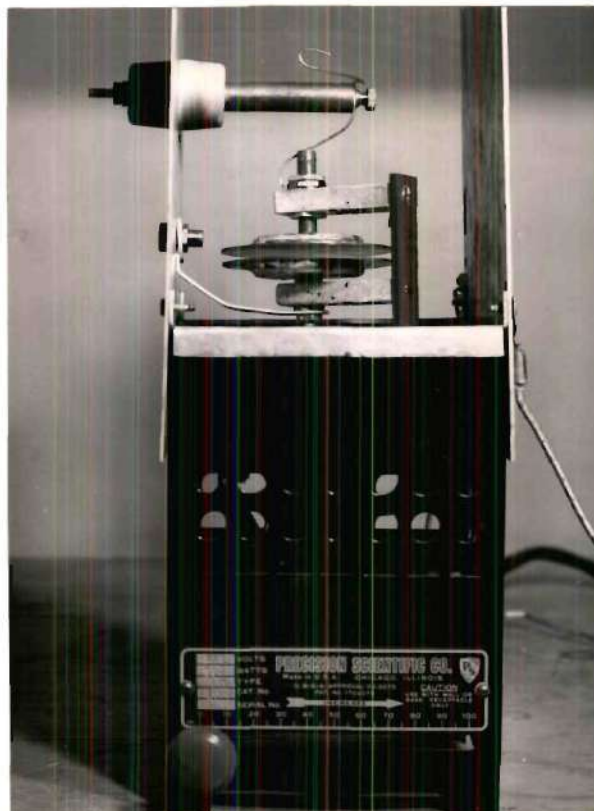


FIG. 6  $K_e$  MEASUREMENT ASSEMBLY



procedure used, a sample calculation is given in Appendix I.

Measurements of  $K_e$  were carried out both at 20,000 cps and 75,000 cps. A Freed Type 1030 low frequency Q-meter was used at 20,000 cps, and a Boonton Model 160A Q-meter was used at 75,000 cps. The results are tabulated in Table I. The results indicate no noticeable change in the dielectric constant of electrets in the direction of polarization as compared to the nonpolarized material. The slight differences between the constants obtained are due to inaccuracies of the instruments and - particularly at the lower frequency - the inability to read a sharp resonant point. The values of dielectric constant measured for the nonpolarized material was in agreement with the values given in the literature. It is believed that enough readings were taken to indicate that if there is a change in the dielectric constant it is of a minute magnitude.

Gutman<sup>1</sup> indicates that there may be a rise to a maximum in the dielectric constant in going from the polarized state to the nonpolarized state by heating, but he gives no evidence of having checked this fact. To investigate this possibility the author of this thesis proceeded in a manner similar to that described above, with the exception that the parallel plates containing the electret under test were placed over the oven used in producing the electrets. The assembly is illustrated in Fig. 6. The temperature was raised slowly and readings were

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<sup>1</sup>F. Gutman, "The Electret," Reviews of Modern Physics, 20: 457, 1948.

TABLE I

## DIELECTRIC CONSTANT TABLES

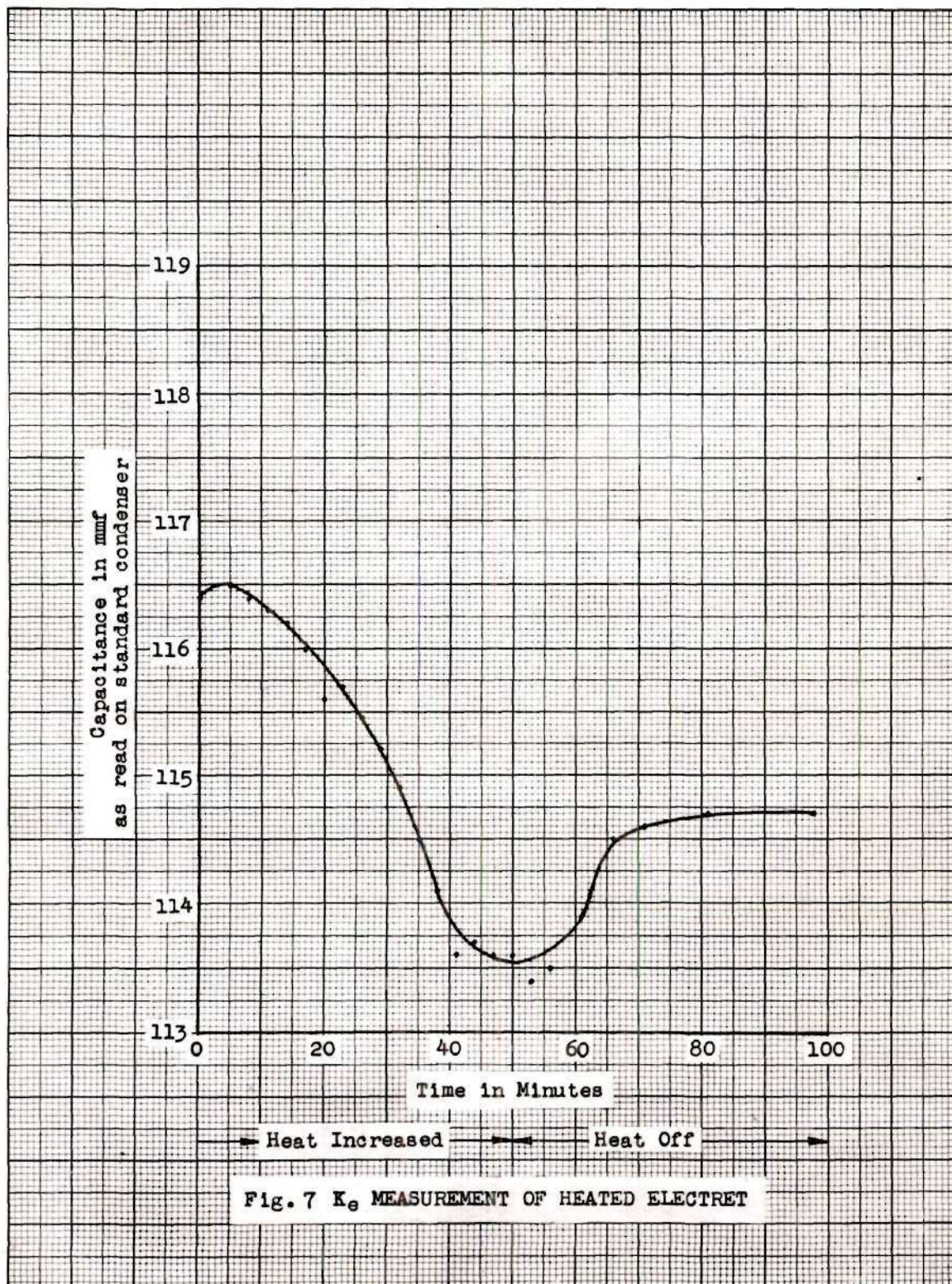
<u>RUN</u>	<u>MATERIAL</u>	<u>DIELECTRIC CONSTANT <math>K_e</math></u>	<u>AVERAGE DIELECTRIC CONSTANT <math>K_e</math></u>
Run #1 Humidity 22% 75,000 cps	Flexiglass #1	2.82	2.76
	Flexiglass #3	2.71	
	Electret #24	2.61	2.67
	Electret #23	2.61	
	Electret #22	2.71	
Run #2 Humidity 43% 75,000 cps	Flexiglass #1	2.94	2.88
	Flexiglass #3	3.06	
	Flexiglass #4	2.83	
	Flexiglass #5	2.71	
	Electret #24	2.71	2.75
Run #3 Humidity 43% 20,000 cps	Electret #23	2.83	
	Electret #22	2.71	
	Flexiglass #1	3.19	3.00
	Flexiglass #3	2.94	
	Flexiglass #4	2.94	
	Flexiglass #5	2.94	
	Electret #24	2.71	2.84
	Electret #23	2.88	
	Electret #22	2.94	

The following are the values of dielectric constant for methyl methacrylate polymer (plexiglass) as given in Technical Data on Plastics, Washington, D.C.: Plastics Material Manufacturers Association, Inc., 1948. 46 pp.

<u>Frequency</u>	<u>Dielectric Constant</u>
60 cps	3.5-4.5
1000 cps	3.0-3.5
1 megacycle	2.7-3.2
3000 megacycles	2.5-2.7

taken continually until the electret was completely depolarized. (Readings were taken only of the capacitance of the parallel plates with an electret between them, as the electret could not be continually removed to obtain the capacitance of the plates with air as the dielectric. However, one capacitance reading of the parallel plates with air as the dielectric was taken before the test while the plates were cool, 118.8 mmf, and one was taken after the test before the plates had completely cooled, 116.2 mmf.) The results are plotted in Fig. 7. The ordinate represents the capacitance reading of the standard condenser which was decreased as the capacitance of the parallel plates increased. The graph indicates that as the heat was applied there was a continual, smooth rise in capacitance of the parallel plates, but that upon removal of the heat the value began to drop again. The results show that there was no observed rapid change in the dielectric constant of the plexiglass electret in changing from the polarized to the nonpolarized state. The variation in the capacitance readings was apparently due to the changes in physical size and spacing of the parallel plates caused by the change in temperature. This is substantiated by the fact that the capacitance of the parallel plates with all air dielectric was different when cool before the test and while still hot after the test.







## V

## OTHER OBSERVATIONS

A number of methods have been suggested in the literature for the measurement of the "equivalent" charge on the surfaces of the electrets. The author used two methods: one with a commercial electrostatic voltmeter (electrometer type) and the other with an electrostatic voltmeter (electroscope type) made along a design given by MacNeice<sup>2</sup>, Fig. 8.

In both instances a metal support was attached directly to the ground terminal of the instrument and the electret was placed on the support. The other terminal was connected through a flexible wire to a metal disk with a diameter exceeding that of the electret. This disk was attached to an insulating rod for handling purposes. The assembly is illustrated in Fig. 9.

To measure the charge the disk was lowered onto the surface of the electret and the meter reading in volts was recorded. The capacitance of the entire assembly was measured. The method used in the capacitance measurement is described in Appendix II. Using  $\sigma = \frac{CV}{A}$  the charge density can then be calculated; where  $\sigma$  is the total charge density on the electret, V is the voltage as indicated by the electrostatic voltmeter, C is the capacitance of the charge measuring

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<sup>2</sup>G. G. MacNeice, "A Simple High-Resistance Electrostatic Voltmeter," Journal of Scientific Instruments and of Physics in Industry, 25: 189, 1948.



FIG. 8 ELECTROSTATIC VOLTMETER  
(ELECTROSCOPE)

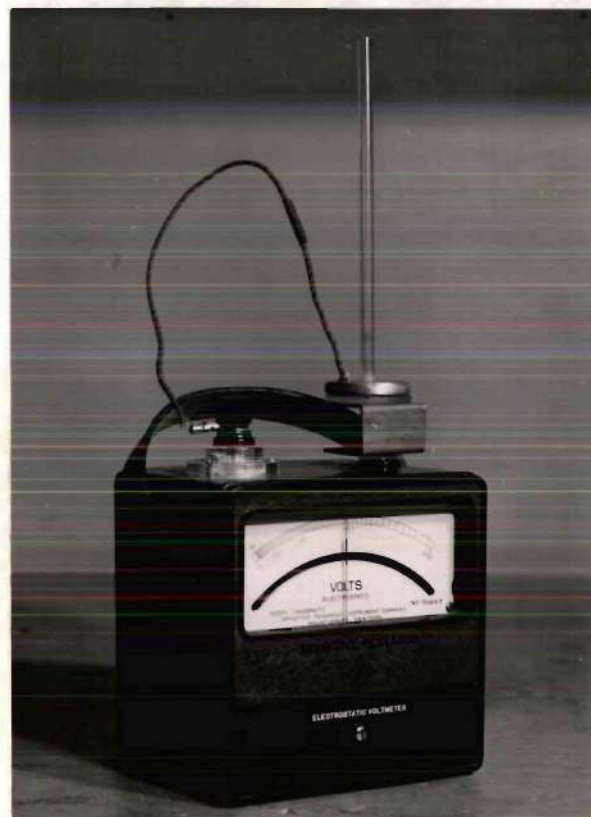


FIG. 9 ELECTROSTATIC VOLTMETER  
(ELECTROMETER)



assembly plus the capacitance of the voltmeter when the scale indicates the voltage  $V$ , and  $A$  is the area of one surface of the electret. The results for a number of electrets of all three types over a period of time are tabulated in Table II. Sudden falling off of the charge density of an electret was generally due to insufficient care in the handling of the electret.

Plexiglass gives a charge density up to twice that of any of the wax combinations tested. The strong charges exhibited and desirable physical properties of plexiglass electrets should make them very desirable for many applications.

In the course of this research Dr. Joseph Dalla Valle of the Chemical Engineering Department became interested in the possible uses of electrets in cloud chambers. Suspended in the cloud chamber were particles which were known to be either neutral or to have a negative charge. Dr. Dalla Valle's idea was to grind an electret to a fine powder and spray it into the chamber. If each small particle of the electret was still polarized it would combine with any charged particles in the chamber and could be settled out.

An electret was made of pure rosin which is very brittle and could be pulverized in a mortar to minute size. The particles were then observed through a microscope, and in one case it was found that by tapping the microscope slide the particles could be lined up end to end as though they were still polarized. This lining up of particles could not be obtained again when photomicrographs were made, and further investigations will have to be made to determine if ground up particles of an electret are still polarized. Two photomicrographs of particles

TABLE II

## CHARGE DENSITY MEASUREMENTS

Note: The numbers under the word "TIME" indicate the number of days that had passed since the production of the electret. The numbers under the word "FRONT" and "BACK" indicate the charge density in micro-coulombs/meter<sup>2</sup> on the front and rear surface of the electret.

PLEXIGLASS ELECTRET #21		
TIME	FRONT	BACK
2	8.57	5.40
7	6.05	4.97
8	2.68	2.68
14	4.97	2.68
16	4.48	2.68
21	3.40	3.40
29	2.68	2.01
31	1.32	2.01

PLEXIGLASS ELECTRET #23		
TIME	FRONT	BACK
1	13.23	9.63
4	10.87	11.57
5	8.70	8.70
11	4.95	4.16
13	4.85	3.47

PLEXIGLASS ELECTRET #24		
TIME	FRONT	BACK
1	17.07	23.00
7	11.30	14.10
9	11.07	13.77
14	8.37	12.50
22	7.07	11.30

CARNAUBA WAX PARAFFIN ELECTRET #1		
TIME	FRONT	BACK
92	1.32	3.40
105	14.00	0.00
115	8.33	0.00
121	7.80	0.00
134	9.80	4.14

CARNAUBA WAX PARAFFIN ELECTRET #2		
TIME	FRONT	BACK
89	6.05	5.40
102	6.05	6.05
112	2.68	6.42
131	6.05	5.54

CARNAUBA WAX 100% ELECTRET #3		
TIME	FRONT	BACK
89	4.77	0.00
102	9.37	4.14
112	0.00	7.97
118	5.40	3.40
131	4.14	4.48

CARNAUBA WAX ROSIN ELECTRET #19		
TIME	FRONT	BACK
1	2.68	0.00
3	0.00	7.80
14	0.00	7.27
21	0.00	9.80
24	0.00	7.60
30	0.00	9.80
35	1.32	9.80
43	1.32	10.67

CARNAUBA WAX BEESWAX ELECTRET #9		
TIME	FRONT	BACK
71	2.01	8.93
84	0.00	4.48
94	0.00	2.68
113	0.00	3.40

from a ground up rosin electret are shown in Fig. 10.

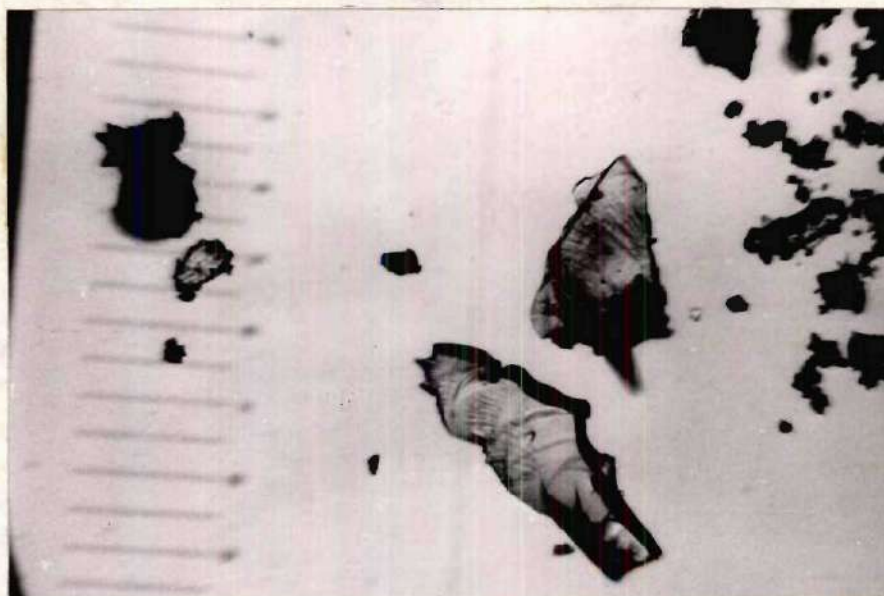
It may prove possible, and more practical, to first grind the desired material into fine particles and then polarize them in the presence of a large electrostatic field and at a temperature that would not cause the particles to melt together. If this proves possible it will open up another field of endeavor to which electrets can be placed; that of micromeritics.

Assuming that electrets may have many properties similar to magnets, the author subjected them to shock tests. It was thought that the electrets would lose their charge, much as a magnet will lose its magnetism if hit with a hammer. To prevent the hammer from affecting the surface by intimate contact, the electret was wrapped in its aluminum foil cover while being subjected to the blows. The foil also shielded any outside field from having an influence on the polarization.

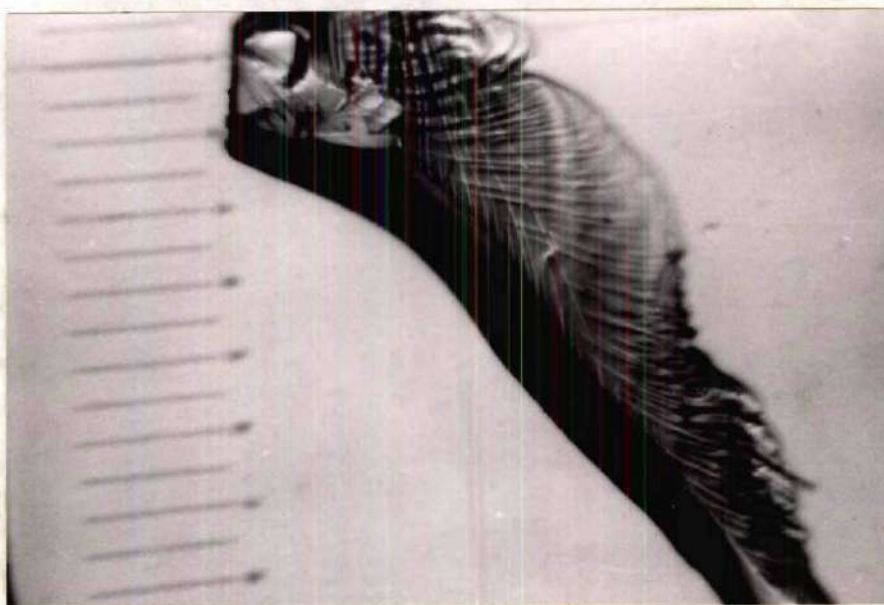
The results were just the opposite to those expected! The charge on the electrets increased each time they were hit. Upon subjecting one of the electrets to continually harder and harder blows, its charge finally reached a maximum and then receded until it reached zero. The results of the shock test on two of the electrets are shown in Fig. 11.

There are at least three possible explanations of this phenomena: 1. Some of the dipoles that are not properly lined up receive sufficient displacement during the blows from the hammer to get in line with the field from the remainder of the dipoles. 2. The pressure from the hammer blows may be sufficient to melt or soften the





MAGNIFICATION 185 DIAMETERS



MAGNIFICATION 150 DIAMETERS

FIG. 10 PHOTOMICROGRAPH - PULVERIZED ROSIN ELECTRET



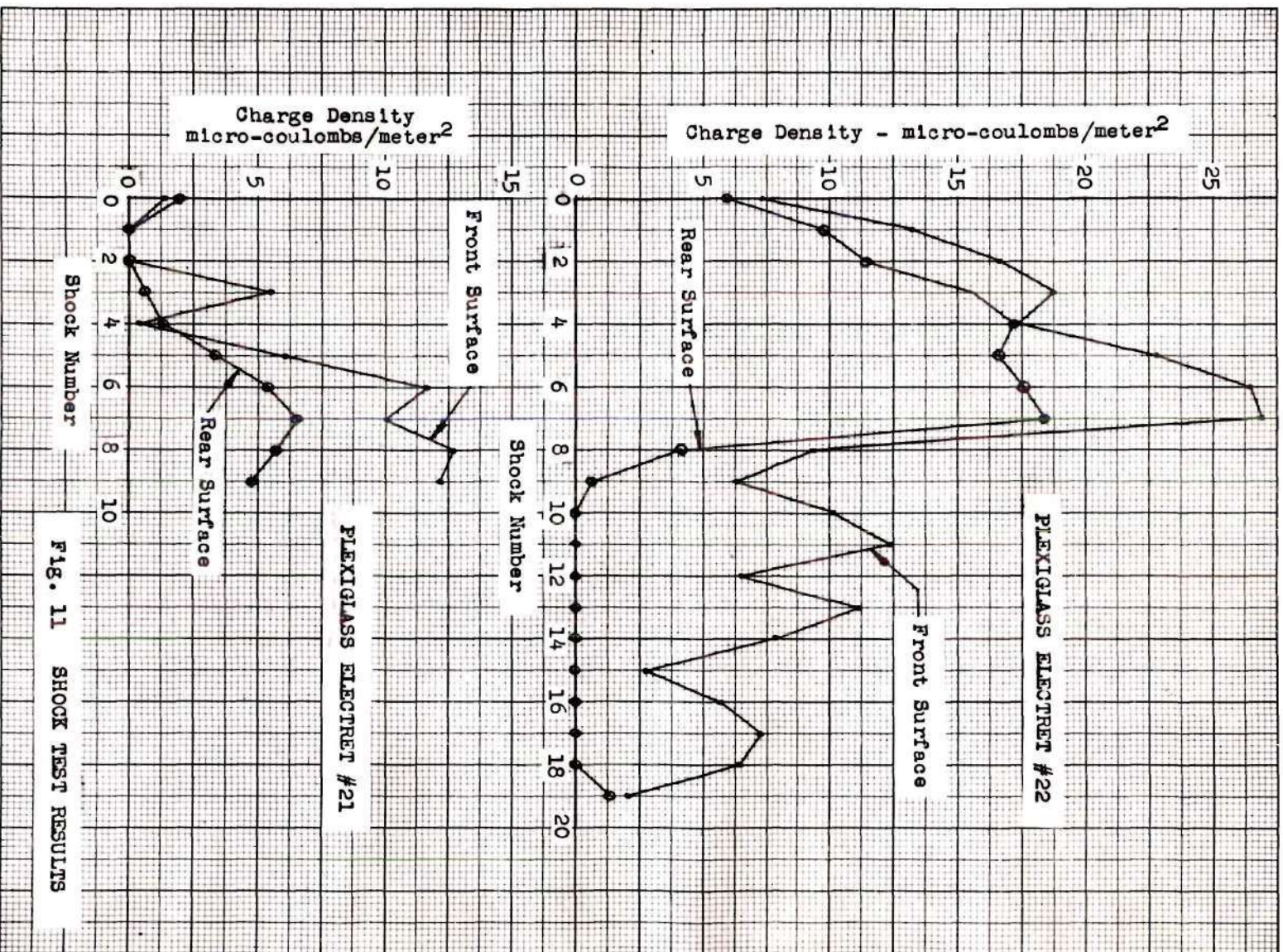


Fig. 11 SHOCK TEST RESULTS

electret, particularly at the surfaces. The surface dipoles that are not lined up are then temporarily "unfrozen" and allowed to line up in the presence of the electret's field. 3. If electrets are crystalline in structure, as is suspected, the hammer blows may break down the crystals to a smaller size in which case there can be more complete alignment of the dipoles. This follows from a similar condition existing with large and small crystals in magnetized materials<sup>3</sup>. A magnetic material composed of small crystals is more easily magnetized than one composed of large crystals.

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<sup>3</sup>  
R. M. Bozorth, Ferromagnetism, New York: D. Van Nostrand Co., 1951. 476 pp.



## VI

## SUGGESTED USES

In pursuing the above work the author and others interested in the work thought of several valuable uses for which electrets may be employed. They are presented here in the hope that others who take up the work may be able to develop these ideas into practical working items.

**Radiation Detector:** In the presence of ionized air the electret temporarily loses its field. This is shown by placing the electret in an X-ray beam. If after being exposed to the ionization, the electret is removed and placed in a metallic wrapper; after a period of time it will regain a charge depending on the original strength of the charge, the material of which it is made, and the amount of exposure to ionization. The design for a suggested radiation detector is illustrated in Fig. 12. It can be made small enough to be carried in one's watch pocket. As long as there is no radiation present to cause ionization of the gas contained in the detector, the aluminum leaf is held against the electret by the electrostatic field. Upon exposure to radiation, the gas ionizes, the field weakens, and the leaf falls away. To "re-charge" the detector it is placed in a position so that the leaf rests on the electret surface. This provides a completed path for the electrostatic field and aids the electret in regaining its charge. The amount of radiation that would be required to operate the detector could be regulated by the weight of the leaf, the strength and size of the electret, and the gas used. It could be made variable in its detection

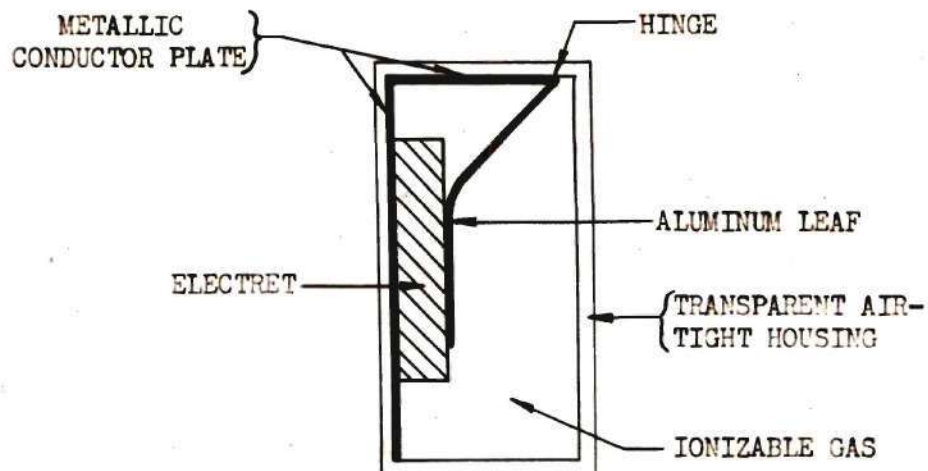


FIG. 12 RADIATION DETECTOR

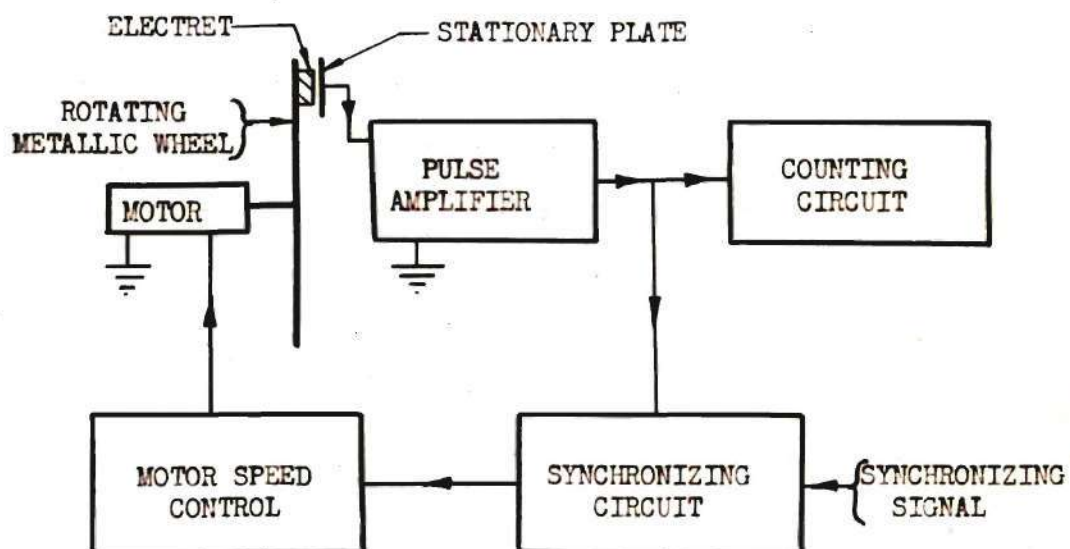


FIG. 13 RPM COUNTER & SYNCHRONIZER

by mechanical arrangements to change the weight of the leaf; thus, each setting would be used to detect different types or amounts of radiation.

**RPM Counter and Synchronizer:** Problems arise where it is desired to determine very accurately the speed of a revolving device or to synchronize an apparatus with a revolving device so that the apparatus will operate at a specific instant in the rotation of the device. A method of accomplishing this synchronization with the use of an electret was suggested by Mr. William Clary, of the School of Electrical Engineering at the Georgia Institute of Technology.

A block diagram of the counter is shown in Fig. 13. An electret is firmly attached to the rotating wheel. At one point in its circular path it passes close to a stationary metal plate which is connected electrically to a pulse amplifier. Each time the electret passes the plate a pulse is induced in the plate and the pulse is then sent through the circuit as indicated. Some of the uses would be: synchronizing rotating filters in color television transmitters and receivers, accurately counting the rpm of a motor, etc.

**Speakers:** As mentioned in the beginning of this thesis, electrets can be used for microphones. This was tried by the author with very good success. The only frequency limiting factor is the mechanical design of the diaphragm and supporting structure. The microphone was then operated as a speaker with equal success. Excellent results should be obtained from an electret speaker with proper design of the cone and supporting structure.

Other uses will suggest themselves to the experimenter. These

uses can be based on the following properties of the electret: the electrostatic field surrounding the electret; its tendency to lose its charge when exposed to ionization at its surface or in the presence of contamination at its surface; and its ability to recharge itself when surrounded by conductor material.



## VII

## SUMMARY AND CONCLUSIONS

This investigation indicates that plexiglass, or similar plastics, show greater possibilities for use as electrets than do the waxes which have been tested. The desirable properties of plexiglass electrets are their greater charge density, their inherent mechanical strength, and their high melting point.

The author was unable to observe any appreciable difference in the dielectric constant of plexiglass in the polarized and non-polarized state. Furthermore, there was no observed change in the dielectric constant of plexiglass electrets when they were transformed from the polarized state to the non-polarized state by the application of heat.

An important observation is believed to be the increase in charge density of electrets when they are subjected to mechanical shock. This may prove to be a valuable technique in the future manufacture of electrets. For example, it may be found that a convenient method of applying the shock would be through supersonic vibrations to which a number of electrets could be subjected at one time.

More fundamental facts are needed on electrets such as their stability under conditions of varying temperature, humidity, and aging. This information will determine if electrets can be used with success commercially. There is a need for complete information on electrets similar to the type that is now available on magnets. If electrets should prove to have stable characteristics, then they will have widespread application in the future.

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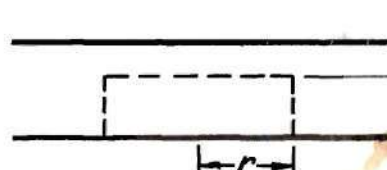


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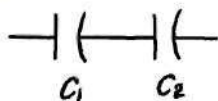
## APPENDIX I

## DIELECTRIC CONSTANT MEASUREMENT FORMULAE

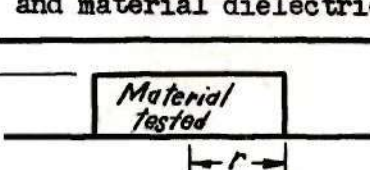
Test assembly condenser  
with all air dielectric



Equivalent circuit



Test assembly condenser  
with combination air  
and material dielectric



Type of deformation of  
completed electret  
(exaggerated)



$C_{sa}$  - capacitance as read on standard condenser with all air dielectric.

$C_{se}$  - capacitance as read on standard condenser with air and electret dielectric.

$C_a$  - calculated capacitance of parallel plates of radius "r" with air dielectric of thickness " $D_t$ ".

$C_1$  - calculated capacitance of parallel plates of radius "r" with air dielectric of thickness " $D_a$ ".

$C_c$  - calculated capacitance of parallel plates of radius "r" with air dielectric of thickness " $D_a$ " in series with electret dielectric of thickness " $D_e$ ".

$C_2$  - calculated capacitance of parallel plates of radius "r", spacing between plates of " $D_e$ ", and electret dielectric of thickness " $D_e$ ".

$C_b$  - calculated capacitance of parallel plates of radius "r", spacing between plates of " $D_e$ " and air dielectric.

$K_e$  - dielectric constant of electret and plexiglass wafer

Dimensions are as indicated in the diagrams above.

$$C_a = \frac{(.2246)(\pi)(r^2)}{D_t} \text{ mmf} \quad C_1 = \frac{(.2246)(\pi)(r^2)}{D_a} \text{ mmf}$$

$$C_c = C_a + (C_{sa} - C_{se}) \text{ mmf} \quad C_2 = \frac{C_1 C_c}{C_1 + C_c} \text{ mmf}$$

$$C_b = \frac{(.2246)(\pi)(r^2)}{D_e} \text{ mmf} \quad K_e = \frac{C_2}{C_b}$$

### SAMPLE CALCULATION

Measured with micrometer:

$$r = .75 \text{ in.} \quad D_a = .040 \text{ in.} \quad D_e = .125 \text{ in.} \quad D_t = .165 \text{ in.}$$

$$C_a = \frac{(.2246)(\pi)(.75)^2}{(.165)} = 2.41 \text{ mmf}$$

$$C_1 = \frac{(.2246)(\pi)(.75)^2}{(.04)} = 9.93 \text{ mmf}$$

Read off standard condenser:

$$C_{sa} = 123.1 \text{ mmf} \quad C_{se} = 121.0 \text{ mmf}$$

$$C_c = 2.41 + (123.1 - 121.0) = 4.51 \text{ mmf}$$

$$C_2 = \frac{(9.93)(4.51)}{9.93 + 4.51} = 8.26 \text{ mmf}$$

$$C_b = \frac{(.2246)(\pi)(.75)^2}{.125} = 3.175 \text{ mmf}$$

$$K_e = \frac{8.26}{3.175} = \underline{2.605}$$

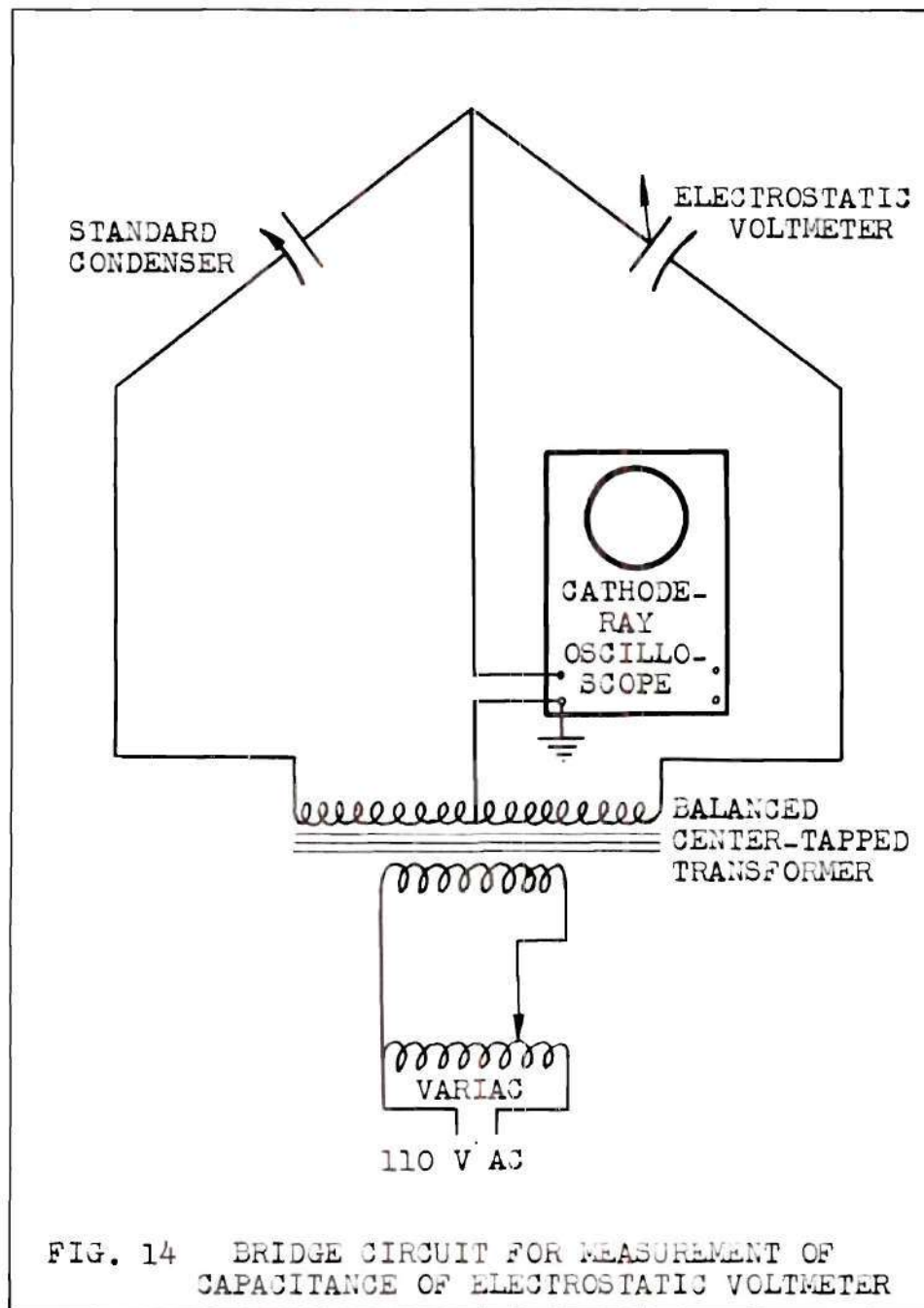


## APPENDIX II

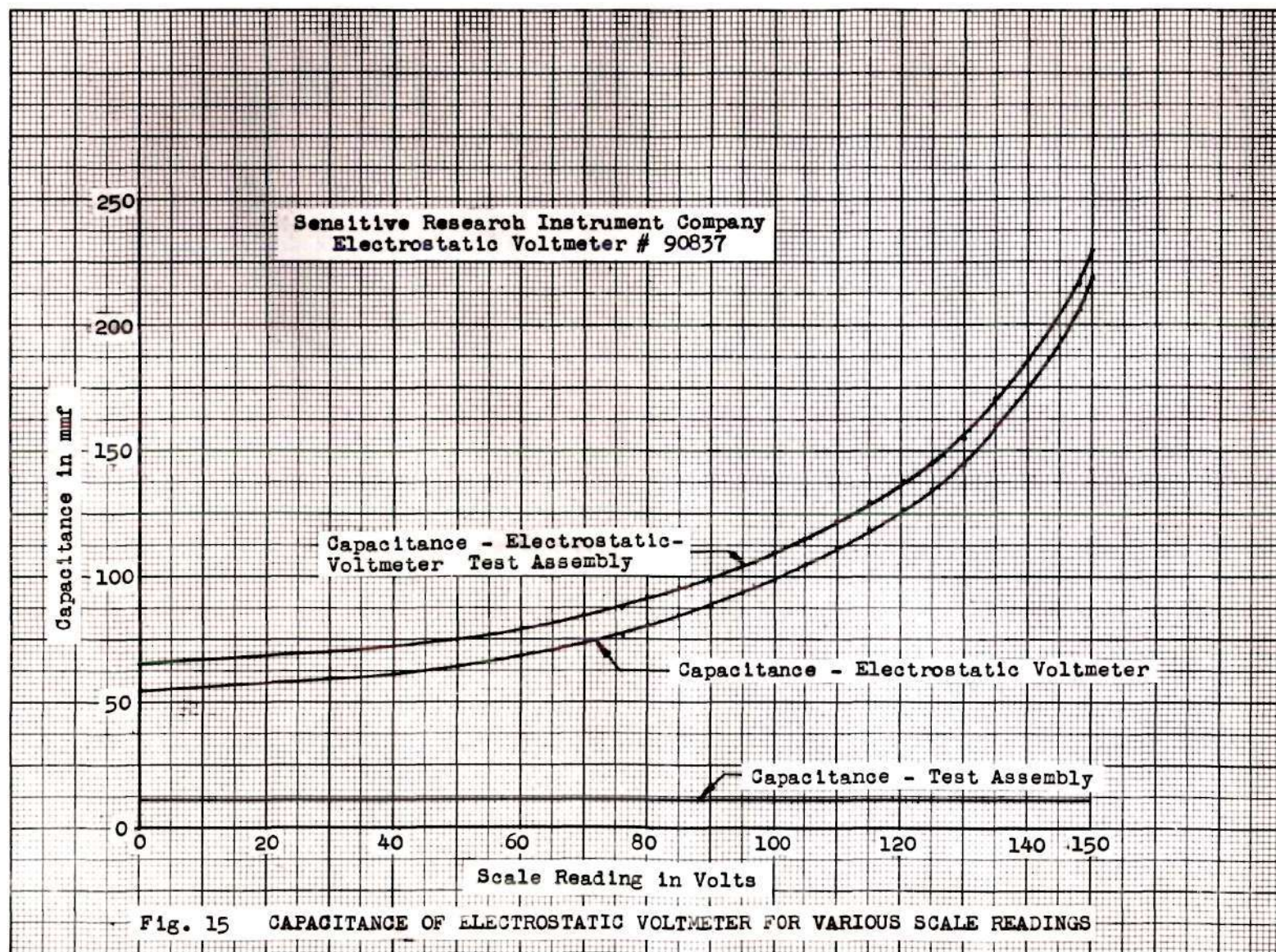
## MEASUREMENT OF CAPACITANCE OF CHARGE MEASURING APPARATUS

In this measurement it was necessary to know the capacitance of the setup illustrated in Fig. 9. The capacitance of the electret platform, disk, and connecting wire could be measured on any ordinary bridge, or by the same method used in obtaining the dielectric constant measurements, but the electrostatic voltmeter capacitance had a different value at each scale reading. Since the meter used was very delicate, it was not desirable to open it and manually adjust the movement to different scale readings and take capacity measurements. Therefore, the bridge circuit illustrated in Fig. 14 was used.

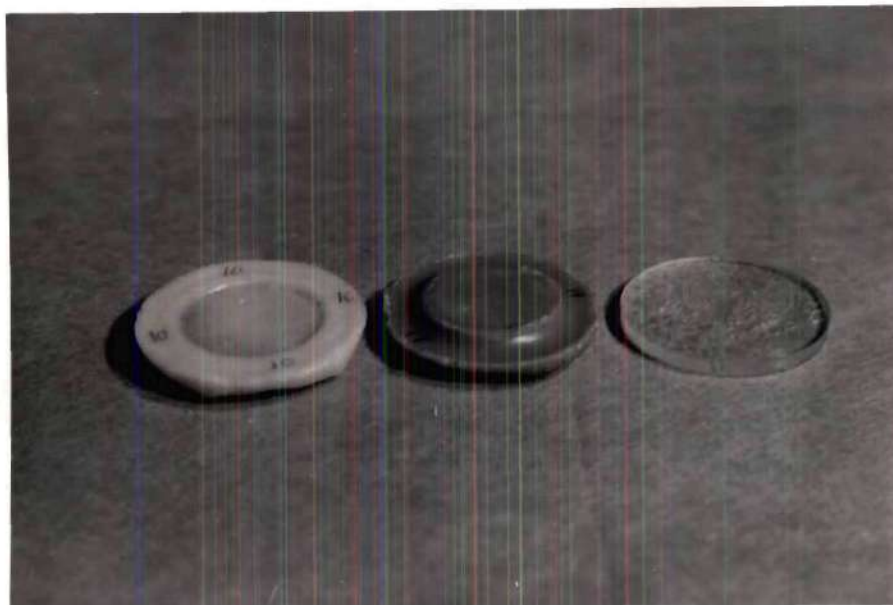
It is seen that when the bridge is balanced, half of the voltage across the transformer appears across the voltmeter. Different voltmeter readings can be obtained by varying the input voltage with the Variac. The bridge is kept in balance by varying the standard condenser. The capacitance of the meter for each scale reading is read directly from the standard condenser. A graph of the meter capacitance versus dial readings is shown in Fig. 15.











CARNAUBA WAX  
& BEESWAX  
ELECTRET

CARNAUBA WAX  
& ROSIN  
ELECTRET

PLEXIGLASS  
ELECTRET

NOTE: The numbers appearing near the edges of the electrets are for identification purposes. The top surface contour of wax electrets is determined by the height of the top electrode and the quantity of wax in the bottom electrode dish during production of the electret.

FIG. 16 SAMPLE ELECTRETS